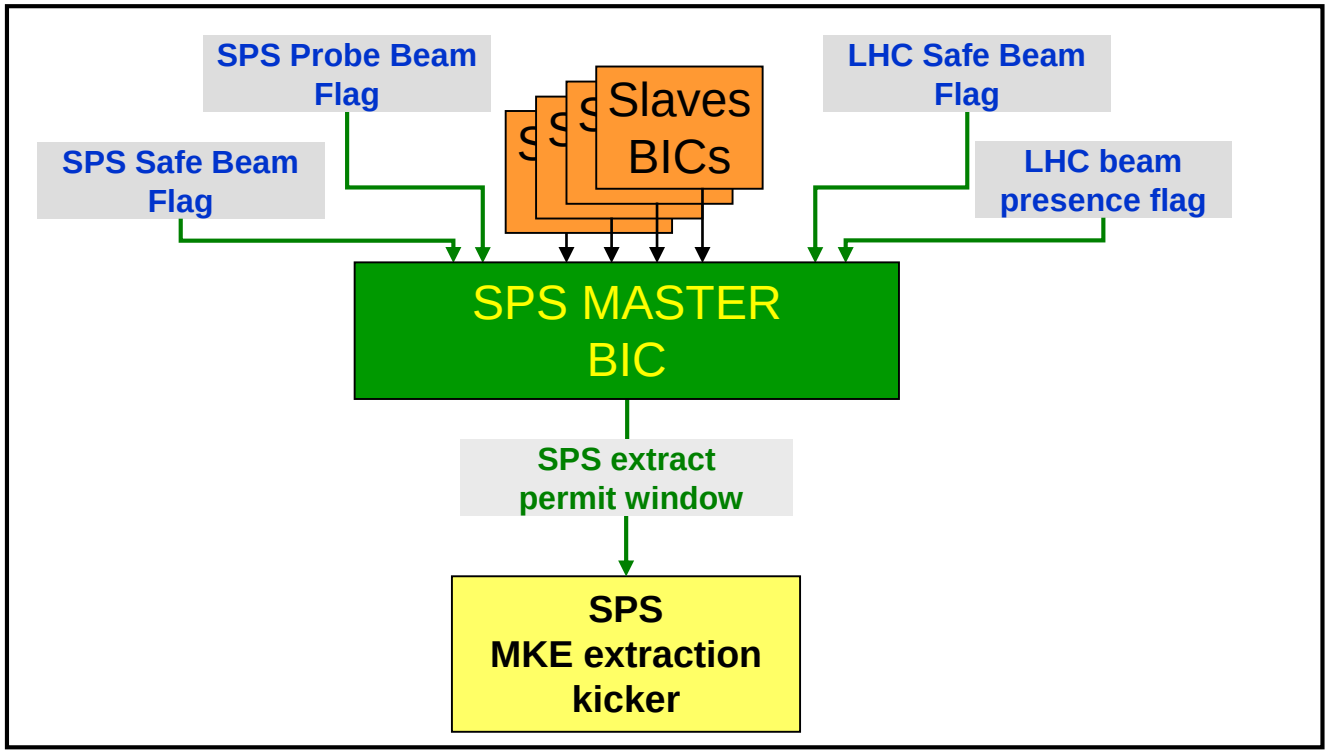
Introduction

- The SPS extraction interlock system prevents that beam is extracted and transferred to LHC if the conditions are not correct
- The extraction interlock system receives flags, and decides if extraction is permitted. The flags are updated between 1Hz and 1000Hz.



Rules to extract beam from SPS to LHC

- In the SPS there is beam with less than **10^{11}** protons. In this case: ProbeBeamFlag=TRUE
- If the LHC is empty the BeamPresenceFlag=FALSE
  - No injection of beam with an intensity above 10^{11} protons is permitted
  - Extraction from SPS only if ProbeBeamFlag=TRUE
- In the SPS there is beam with less than **10^{12}** protons. The beam is “safe” and SPS_SafeBeamFlag=TRUE (safe for most failure scenarios)
- In the LHC there is beam with less than **10^{12}** protons at injection energy. The beam is “safe” and LHC_SafeBeamFlag=TRUE
  - Safe beam in LHC allows masking part of the interlocks inputs to the BIS. Part of the interlocks can never be masked.
- It is not permitted to inject high intensity beam into LHC if interlock inputs are masked: LHC_SafeBeamFlag=FALSE is required for injecting high intensity beam

All possible combination of flags

SPS Probe beam Flag	**TRUE=1**	**FALSE=0**
SPS Safe beam Flag	**TRUE=1**	**FALSE=0**
Beam Presence Flag	**TRUE=1**	**FALSE=0**
LHC Safe Beam Flag	**TRUE=1**	**FALSE=0**

SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Extraction	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**	**?**

Case 6: Probe beam in SPS, no beam in LHC

SPS Probe beam Flag	**1**
SPS Safe beam Flag	**1**
Beam Presence Flag	**0**
LHC Safe Beam Flag	**1**
Extraction	**YES**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 7: Probe beam in SPS, Safe beam in LHC

SPS Probe beam Flag	**1**
SPS Safe beam Flag	**1**
Beam Presence Flag	**1**
LHC Safe Beam Flag	**1**
Extraction	**YES**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 8: Probe beam in SPS, Unsafe beam in LHC

SPS Probe beam Flag	**1**
SPS Safe beam Flag	**1**
Beam Presence Flag	**1**
LHC Safe Beam Flag	**0**
Extraction	**YES**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 10: Safe beam in SPS, intensity above probe beam, No beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**1**
Beam Presence Flag	**0**
LHC Safe Beam Flag	**1**
Extraction	**NO**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 11: Safe beam in SPS, intensity above probe beam, Safe beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**1**
Beam Presence Flag	**1**
LHC Safe Beam Flag	**1**
Extraction	**YES**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 12: Safe beam in SPS, intensity above probe beam, Unsafe beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**1**
Beam Presence Flag	**1**
LHC Safe Beam Flag	**0**
Extraction	**YES**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 13: Unsafe beam in SPS, No beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**0**
Beam Presence Flag	**0**
LHC Safe Beam Flag	**0**
Extraction	**NO**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 14: Unsafe beam in SPS, No beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**0**
Beam Presence Flag	**0**
LHC Safe Beam Flag	**1**
Extraction	**NO**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 15: Unsafe beam in SPS, Safe beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**0**
Beam Presence Flag	**1**
LHC Safe Beam Flag	**1**
Extraction	**NO**

Extraction requires to toggle the LHC_SafeBeamFlag from TRUE to FALSE, although the beam in the LHC has an intensity below 10^{12} protons (done via sequencer / timing)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 16: Unsafe beam in SPS, Unsafe beam in LHC

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**0**
Beam Presence Flag	**1**
LHC Safe Beam Flag	**0**
Extraction	**YES**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 5: Probe beam in SPS, no beam in LHC, LHC Safe Beam Flag forced to FALSE (condition that is normally not used)

SPS Probe beam Flag	**1**
SPS Safe beam Flag	**1**
Beam Presence Flag	**0**
LHC Safe Beam Flag	**0**
Extraction	**YES**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Case 9: Safe beam in SPS, intensity above probe beam, no beam in LHC, LHC Safe Beam Flag forced to FALSE

(condition that is normally not used)

SPS Probe beam Flag	**0**
SPS Safe beam Flag	**1**
Beam Presence Flag	**0**
LHC Safe Beam Flag	**0**
Extraction	**NO**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Equation

Extraction is allowed if….

ProbeBeam .OR. (BeamPresence .AND. (LHC_UnsafeBeam .OR. SPS_SafeBeam))

Case 1-4: Not allowed, failure

- SPSProbeFlag .AND. SPS_UnsafeBeam (1,2,3,4)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction					YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	YES

Failure scenarios

- Scenario 1:
  PROBE_BEAM_FLAG fails to FALSE, makes the extraction Case 4. NO EXTRACTION! GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, makes a conflict with PROBE_BEAM_FLAG, NO EXTRACTION! GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, a prerequisit for extraction, if there was beam presence we would be allowed the extraction anyway. GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, makes a conflict with BEAM_PRESENCE_FLAG, NO EXTRACTION! GOOD!
- Scenario 2;
  PROBE_BEAM_FLAG fails to FALSE, the extraction is still permitted beacause SPS_SAFE_BEAM is TRUE. GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, creates a conflict, can't be PROBE as well as SAFE, NO EXTRACTION! GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, we can still extraction as it's a PROBE beam, same as Case 1, GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, we can still extract as it's a PROBE, as Case 3, GOOD!

- Scenario 3:
  PROBE_BEAM_FLAG fails to FALSE, LHC already has dangerous beam, so we're allowed, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, conflict PROBE can't be TRUE when SAFE is FALSE, NO EXTRACTION! GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, conflict, can't have SAFE and NOT PRESENCE, NO EXTRACTION! GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, pre-requisit for extraction, we're allowed, GOOD!
- Scenario 4:
  PROBE_BEAM_FLAG fails to FALSE, pre-requisit state, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, same as case 7, no extraction! GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, pre requisit state, no extraction! GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, conflict as can't have SAFE and NOT PRESENT! GOOD!

- Scenario 5:
  PROBE_BEAM_FLAG fails to FALSE, prerequisite state, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, can't extract when LHC SBF is TRUE, no extraction! GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, can't extract above PROBE into empty machine, no extraction! GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, we're extracting a SAFE beam, so it doesn't matter! Extraction allowed, GOOD!
- Scenario 6;
  PROBE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, LHC already has UNSAFE, so it's allowed, GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, can't have UNSAFE beam and NOT PRESENT, no extraction! GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, pre-requist condition, extraction allowed, GOOD!

- Scenario 7;
  PROBE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, pre-requisite condition, GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, can't have UNSAFE and NOT PRESENT, no extraction! GOOD!
- Scenario 8:
  PROBE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, can't have UNSAFE extraction into 'empty' LHC, no extraction! GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, this would allow an extraction, at the moment it was to be forced... BAD? GOOD?
- Scenario 9:
  PROBE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  SPS_SAFE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!
  BEAM_PRESENCE_FLAG fails to FALSE, can't have UNSAFE BEAM and NOT PRESENT, no extraction! GOOD!
  LHC_SAFE_BEAM_FLAG fails to FALSE, pre-requisite condition, GOOD!